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Technical Lesson 34

PRACTICAL RADIO CONSTRUCTION

The Tuned-Grid Tuned-Plate Circuit. Up to the present we have dealt with a number of receivers, each employing a regenerative vacuum tube detector. With one exception, all of these receivers made use of a tickler coil in order to secure the feed-back necessary to regeneration and its allied phenomenon, oscillation. In each instance feed-back was secured by virtue of electromagnetic induction, and the principle difference in these circuits lay in the manner of controlling feed-back. Such control, of course, is necessary in order to maintain the tube at its most advantageous adjustment for the reception of broadcasting, that is, at the point of maximum regeneration.

It is the purpose of this lesson to deal with a circuit arrangement which will give rise to regeneration and oscillation in a vacuum tube, and it is important inasmuch as it has a direct bearing upon the greatest problem encountered in radio-frequency amplification, a subject with which we shall soon concern ourselves. This problem is how to prevent oscillation in a radio-frequency amplifier, and this lesson will serve as an introduction to the causes of oscillation in such circuits.

The circuit dealt with in this lesson is that of a vacuum tube detector and, when properly adjusted, it will enable the user to secure regeneration and oscillation. As a regenerative detector tube circuit it is as sensitive and selective as any heretofore described, but it is of little practical value due to the difficulty encountered in controlling feed-back and for that reason is seldom used today. When it is desired to introduce regeneration into a vacuum tube detector, one of the tickler coil circuits already described is utilized. It is described herein, not because it is especially valuable as a regenerative detector circuit, but because it leads directly to important considerations entering into the functioning of radio frequency amplifiers.

This circuit, which is shown schematically in Figure 1, is known as the tuned-grid tuned-plate circuit; the origin of the name being obvious after a single glance at the schematic wiring diagram. The grid circuit of the tube is tuned by the inductance L_1 and the condenser C_1 , while the plate circuit is tuned by the inductance L_2 and condenser C_2 .

The tube will oscillate readily when the grid and plate circuits are both tuned to the same wavelength; and by de-tuning the plate circuit so that it is no longer tuned to the same wavelength as the grid circuit, the tube can be stopped from oscillating and adjusted to the point of maximum regeneration.

Oscillation takes place despite the fact that there need be no electromagnetic coupling between the plate and grid coils, as was necessary in the other re-

generative detector circuits with which we have dealt. As a matter of fact, in the actual lay-out of the apparatus in the receiver the plate and grid coils are deliberately placed at right angles to each other, thereby reducing the electro-magnetic coupling between them to practically zero. If no electro-magnetic coupling exists between the plate and grid coils it is obvious that no electro-magnetic induction can take place between them and thus effect feed-back from the plate to the grid circuit. Yet the tube oscillates and, therefore, feed-back must in some manner take place; and this feed-back does take place through the inter-electrode capacity of the vacuum tube.

As we proceed with this subject of feed-back through the inter-electrode capacity of a vacuum tube, bear in mind the fact that any two conductors which are fairly close together and insulated from each other are capable of functioning as an electro-static condenser.

Let us consider, then, the placement of the electrodes in a modern vacuum tube. As you know, the tube has three metallic electrodes; a filament, a grid, and a plate. The metal filament is encircled by a wire mesh (the grid) and this, in turn, is surrounded by a metal plate. These electrodes are carefully insulated one from the other and the spacing between any two of them is but a fraction of an inch. Here, then, we have fulfilled the conditions necessary for the formation of an electro-static condenser, as given above; that is, two or more conductors insulated from each other closely spaced.

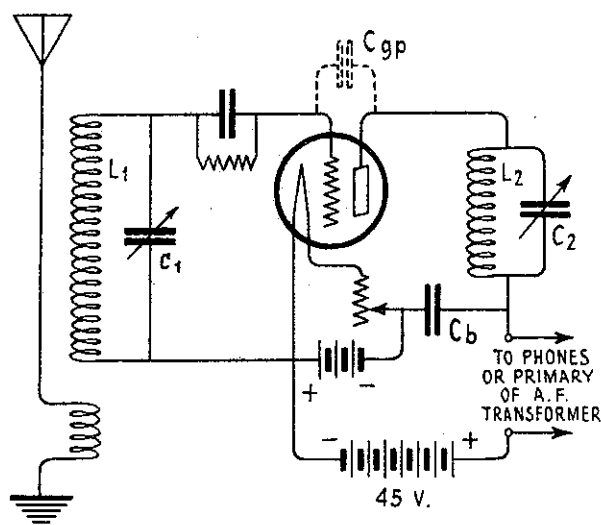


Figure 1.

Three such condenser effects exist within a three-electrode vacuum tube; namely, the plate-filament capacity, grid-filament capacity and plate-grid capacity; and it is the plate-grid capacity with which we are chiefly concerned in this lesson. The presence of the plate-grid capacity is indicated in dotted lines as C_{pg} in the schematic wiring diagram. Bear in mind that no actual condenser is connected between the plate and grid of the tube. Those dotted lines are simply to assist you to visualize the existence of the tube's plate-grid capacity. On the other hand, do not permit the fact that it is shown in dotted lines lead you to believe that this plate-grid capacity is more or less

imaginary or unimportant. It is very real and the complications that arise from its existence has caused more than one radio engineer to burn the midnight oil seeking ways and means of overcoming it.

The plate-grid capacity is very small in the average vacuum tube, being of the order of 0.000008 mfd. for the ordinary 201A type of tube. Small as this capacity is, however, it provides a path for the flow of radio-frequency current from plate to grid of the tube. Any transfer of energy from plate to grid of the tube constitutes feed-back whether it is accomplished inductively, as by the use of a tickler coil, or by means of the electro-static capacity of a condenser. Furthermore, when the feed-back voltage is in phase with (of the same polarity as) the signal voltage being impressed upon the grid of the tube, it strengthens, or reinforces, the signal voltage. Should the opposite be true, that is, should the feed-back be of opposite polarity to the signal voltage, it will weaken the signal even to the point of completely nullifying it. However, the feed-back through the plate-grid capacity is invariably in phase with the signal voltage, so that when the feed-back is sufficiently great, oscillation will result.

Needless to say, no current will flow through a condenser unless voltage is applied to it and, furthermore, such voltage must be of an alternating nature. Therefore, in the case of condenser C_{pg} no current will flow through it because of the voltage impressed upon it by the "B" battery, for the voltage of the "B" battery is steady and unvarying.

However, when an incoming signal impresses its voltage upon the grid of the tube, the consequent radio-frequency variations in the plate current do, in effect, cause a radio-frequency variation of the plate potential. Or, in other words, the radio-frequency voltage impressed upon the grid of the tube causes a corresponding radio-frequency potential to appear in the plate circuit. This radio-frequency variation of the plate potential is impressed upon the tiny condenser formed by the plate and grid, and the net result is feed-back through this capacity from plate circuit to grid circuit; the amount of feed-back depending principally upon the strength of the radio-frequency voltage present in the plate circuit.

Ordinarily this voltage is not great enough to cause sufficient feed-back for regeneration and oscillation and, therefore, this feed-back via the plate-grid capacity must be supplemented by additional feed-back secured in other ways as, for instance, by means of a tickler coil.

But if the radio-frequency voltage present in the plate circuit can be strengthened sufficiently, then the feed-back due to the plate-grid capacity will be increased to the point where regeneration and oscillation will result without the presence of any feed-back other than that which takes place by virtue of the plate-grid capacity.

This can be done by including in the plate circuit an inductance, L₂, and tuning this inductance by means of a condenser, C₂, to resonance with the particular radio-frequency being dealt with.

When radio-frequency current flows through the inductance L_2 , the magnetic lines of force surrounding this coil rise and fall in accordance with the variations in current strength and, in so doing they create a secondary, or self-induced voltage. The strength of this self-induced voltage, which is often termed the inductive reactance voltage, depends primarily upon the value of the inductance and the strength of the current flowing therein. In this instance, the value of inductance L_2 is determined and fixed by the wavelength range to be covered when used with condenser C_2 of a given capacity. Therefore, the strength of the inductive reactance voltage will depend upon the strength of the r.f. current flowing through this inductance.

Inasmuch as the inductance L_2 and condenser C_2 form an oscillatory circuit, the greatest flow of radio-frequency current will take place in this circuit when it is tuned to resonance with the radio-frequency current flowing in the plate circuit. The inductive reactance voltage developed across the inductance, L_2 , will then be at its maximum value and will result in maximum feedback through the plate-grid capacity, and this feedback will be sufficient to cause the tube to oscillate.

If the oscillatory circuit, L_2C_2 , is de-tuned from resonance with the radio-frequency component of the plate current, the radio-frequency current flowing in circuit L_2C_2 will, of course, decrease and therefore the inductive reactance voltage developed across L_2 will decrease. Any reduction of this voltage developed across L_2 means a reduction of the voltage applied to the plate-grid capacity, C_{pg} , which in turn results in a decrease in feedback. When the plate circuit is de-tuned sufficiently the feedback will be reduced to the point at which the tube ceases to oscillate and becomes regenerative. Thus, the tuning of the plate circuit becomes a regeneration control for, by adjusting the degree of resonance of the tuned plate circuit, L_2C_2 , the tube can be made to oscillate or to regenerate.

Before commencing the wiring of this receiver it will be necessary to mount an additional piece of apparatus upon the baseboard, i.e., the tuned radio frequency transformer. This instrument should be mounted near the rear left-hand corner of the baseboard and, furthermore, it should be placed at right angles to the three-circuit tuner mounted upon the panel. By so placing the radio-frequency transformer, inductive coupling between it and the three-circuit tuner is reduced to a minimum.

Having mounted the RF transformer, begin wiring by connecting its primary (the small coil of ten turns of wire) to the antenna and ground binding posts. Connect a wire between the $+A$ binding post on the terminal strip and the positive filament terminal of the tube socket. The $-A$ binding post on the terminal strip is now connected to a terminal of the detector's filament rheostat and the other terminal of this rheostat is connected to the negative filament terminal of the tube socket. Connect the grid condenser to the grid terminal of the tube socket. The grid leak is, as usual, inserted in the clips provided for it on the grid condenser. The secondary of the tuned RF transformer is the larger of the two coils comprising this instrument. The end of the secondary which is next to the primary coil, i.e., the "low" end, should be connected to the positive filament lead. The end of the secondary

coil opposite the primary coil, i.e., the "high" end, should be connected to the grid condenser. The variable tuning condenser mounted at the left of the panel should now be connected in parallel to the secondary of the tuned RF transformer. When doing this be careful to connect the stator plates of the condenser to the "high" end of the secondary and the rotor plates to the "low" end of the secondary.

Of the three coils which comprise the three-circuit tuner only the secondary is made use of in this circuit, the primary and tickler coils being left disconnected. A connection is now made between the plate terminal of the tube socket and one of the secondary terminals of the three-circuit tuner. The other secondary terminal is connected to a tip-jack. The remaining tip-jack is connected to the B+Det binding post on the terminal strip. The variable tuning condenser which is mounted to the right of the panel should now be connected in parallel to the secondary coil of the three-circuit tuner. In doing this it would be advisable to connect the stator plates of this condenser to that end of the secondary coil which is connected to the plate terminal of the tube socket. The rotor plates should then be connected to the opposite end of this (secondary) coil. The 0.001 mfd. fixed condenser is the by-pass condenser shown as C_b in Figure 1. One terminal of this condenser is connected to the filament circuit as shown, while its other terminal is connected to the same tip-jack to which one terminal of the three-circuit tuner secondary is connected.

When the apparatus is connected in accordance with the above instructions, the secondary of the RF transformer becomes the grid coil, L_1 , and the tuning condenser connected in parallel to this coil is the grid tuning condenser, C_2 . Also, the secondary of the three-circuit tuner is the plate tuning coil, L_2 , and the variable condenser in parallel to this coil is the plate tuning condenser, C_2 .

As in previous lessons, if the audio-frequency amplifier is used, as recommended, the wires connecting to the two tip-jacks are connected instead to the primary terminals of the first AF transformer. Take care that the wire which connects to the B+Det binding post on the terminal strip is connected to the B terminal of the AF transformer. The plate terminal of the tube socket should be connected, through the inductance L_2 , to the P terminal of the AF transformer.

The operation of this receiver does not differ greatly from that of other types of regenerative detectors. There are two controls, namely, the variable condenser, C_1 , which enables the user to tune the grid circuit of the tube to the wavelength of the desired signal; and the variable condenser, C_2 , which serves to tune the plate circuit of the tube, and which functions as a regeneration control.

Oscillation takes place when the grid circuit, $L_1 C_1$, and the plate circuit, $L_2 C_2$, are both tuned to the same wavelength. Oscillation in the detector tube can be controlled by de-tuning the plate circuit from resonance with the frequency of the incoming signal, and so, by proper manipulation of the plate tuning condenser, C_2 , the detector tube can be adjusted to the point of maximum regeneration.

Changes in the tuning of the plate circuit are apt to effect the tuning of the grid circuit. Therefore, when altering the tuning of the plate circuit in order to adjust the detector tube to the point of maximum regeneration, it will be necessary to make minor re-adjustments in the tuning of the grid circuit in order to keep this circuit in resonance with the desired signal.

The secondary of the tuned RF transformer, L_1 and the secondary of the three-circuit tuner, L_2 are very nearly alike in their values of inductance; and the same holds true for the two variable tuning condensers, i.e., for any given setting they will be nearly alike in their values of capacity. Therefore, when the dials of the tuning condensers read alike, the two tuned circuits which these condensers control will be tuned to practically the same wavelength, and oscillation will result.

The grid circuit of the tube, L_1C_1 , must be tuned to exact resonance with the signal it is desired to receive. To stop the tube from oscillating and adjust for maximum regeneration, de-tune the plate circuit.

Decreasing the filament current of the detector tube below its normal value will prove of material aid in preventing oscillation; thus, the detector tube rheostat can be used as a supplementary oscillation control by which the tube can be adjusted for maximum regeneration. Do not, however, decrease the detector tube's filament current too much, because too great a decrease in its value will greatly impair the sensitivity of the tube. On the other hand, care should be exercised not to increase the filament current of the detector tube, or any tube for that matter, above its normal value, for by so doing the life of the filament will be shortened. The exact manner in which the detector rheostat can be used in adjusting the detector tube for maximum regeneration can best be determined by experiment. It should be borne in mind, however, that the plate tuning condenser, C_2 is the main oscillation control and the detector filament rheostat should only be used to secure the final adjustment of regeneration.

Tuning the Plate Inductively. The circuit with which we shall deal in the following paragraphs is a continuation of the receiver just described in the preceding pages of this lesson. That the two circuits are quite similar is at once evident from a comparison of Figure 2 and the circuit diagram, Figure 1, yet the circuit shown in Figure 2 incorporates an elaboration of the preceding hook-up which is of prime importance in tuned radio-frequency amplification. The manner in which these two circuits differ from each other lies in the fact that the tuned oscillatory circuit, L_2C_2 instead of being directly connected into the plate circuit of the detector tube, is coupled to the plate circuit by means of coil P. Despite the fact that the tuned oscillatory circuit, L_2C_2 is no longer connected in the plate circuit of the detector tube, nevertheless it serves to tune the tube's plate circuit due to the fact that it is coupled thereto.

It is a well known fact that when two such oscillatory circuits are placed in inductive relationship to each other, the electrical characteristics of each will influence the electrical characteristics of the other. Incidentally, it might be well to mention that by "electrical characteristics" is meant resistance, inductance and capacity and the allied phenomenon of resonance

arising from their inter-related functionings. The extent to which electrical characteristics of the coupled circuits involved will influence each other will depend to a great extent upon the degree of coupling existant between these circuits. To elaborate upon the foregoing statement let us state that if the coupling between the circuits is tight their effect upon each other will be pronounced, while if the coupling is loose this mutual reaction between the circuits will be less evident; and when the coupling between them is made very loose their reaction upon each other becomes negligible.

Consider, then, the coil P, Figure 2, and the tuned oscillatory circuit, L_2C_2 . You will note that no provision has been made for tuning coil P, and, by disregarding its natural period or wavelength, we may consider it, as far as our purposes are concerned, as being untuned. This coil is inductively coupled to coil L_2 , which, in conjunction with the variable condenser, C_2 forms an oscillatory circuit. By virtue of the values of inductance and capacity of L_2 and C_2 respectively, this tuned circuit may be resonated to any wavelength between 200 meters and 550 meters by varying the capacity of the variable condenser C_2 .

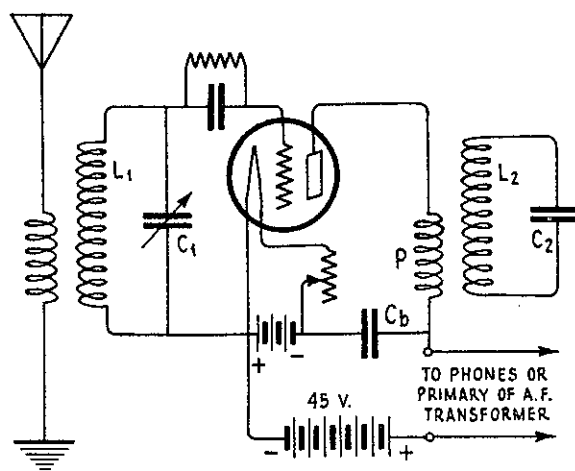


Figure 2.

Because of the inductive coupling between coil P and the oscillatory circuit, L_2C_2 , the tuning of this oscillatory circuit will make itself felt upon coil P and, in effect, will tune coil P to approximately the same wavelength as that to which circuit L_2C_2 is resonated.

In this manner, circuit L_2C_2 serves to tune the plate circuit. Although it is not connected to the plate circuit of the tube by direct wire connection as in Figure 2, it is, nevertheless, connected to the plate circuit by magnetic lines of force, i.e., it is coupled to the plate circuit.

A somewhat different angle from which to regard this phenomenon is from the viewpoint that when dealing with alternating currents, whether they be of high or low frequency, it is not necessary to employ metallic conductors in order to secure a connection between two or more circuits. Direct metallic connections may be dispensed with and the circuits "connected" by utilizing

magnetic lines of force; and when two or more circuits are so connected by magnetic lines of force, they are said to be "inductively coupled".

When circuits are connected by means of metallic conductors the efficacy of such connections is determined by the resistance, or, conversely, the conductivity of such connections. A similar determining factor is encountered when two or more circuits are "connected" by magnetic lines of force, i.e., coupled, inasmuch as the effectiveness of the "connection" is dependent upon the degree of coupling employed.

Thus, even as in Figure 1, circuit L_2C_2 tunes the plate circuit of the tube due to its coupling thereto, and the extent to which its tuning will influence the plate circuit will be determined by the degree of coupling between it and the coil P. If coil P is closely coupled to coil L_2 the influence of circuit L_2C_2 upon the plate circuit will be pronounced, but as the coupling is loosened its influence upon the plate circuit becomes less and less until, when the coupling is made sufficiently loose, the influence of circuit L_2C_2 upon the plate circuit becomes negligible.

When the grid and plate circuits are tuned to the same wavelength and with tight coupling between coils P and L_2 , the tube will oscillate and otherwise behave in a manner similar to that of the preceding hook-up shown in Figure 2. But, in addition to those effects noted in the operation of that receiver, it will be found that adjustment of the coupling between coils P and L_2 provides us with an additional and very effective oscillation control.

To convert the hook-up of Figure 1 to the circuit shown in the wiring diagram of Figure 2, only one simple change in the plate circuit wiring is necessary. To make this change, disconnect from the plate circuit the tuned circuit, L_2C_2 , and substitute for it the coil P. More specifically: Trace the wire that leads from the plate terminal of the detector tube socket to the secondary of the three-circuit tuner (L_2). Disconnect this wire from coil L_2 and connect it instead to one of the terminals of the tickler coil. The wire which leads from one of the tip jacks (or the P terminal of the first stage AF transformer, depending upon whether or not an audio amplifier is used) to the other terminal of coil L_2 is now disconnected from this coil terminal and connected instead to the remaining terminal of the tickler coil. In this way, the coil which was formerly employed as a tickler coil now becomes the primary P of the tuned r.f. transformer composed of the coil P and the tuned secondary coil, L_2 . Moreover, as this primary coil is rotatable, we have a convenient means of varying the coupling between the primary and the secondary coils.

When making the changes described above, care should be exercised that the condenser, C_2 , which is ordinarily connected in parallel to coil L_2 , remains connected to this coil, and that no other changes in the wiring of the plate circuit are inadvertently made except those alterations mentioned.

When first putting the receiver in operation, place the primary (tickler) coil, P, parallel to the secondary coil, L_2 , thus securing the maximum available coupling between the two. Then proceed to operate the receiver as in the preceding lesson. As before, the grid circuit, L_1C_1 , must be tuned to resonance with the desired signal and, with maximum coupling between the coils P and L_2 the detector tube will oscillate when the tuned plate circuit is brought into resonance with the grid circuit. As in the receiver first described (Figure 1), oscillation can be stopped and the tube adjusted for maximum regeneration by de-tuning the plate circuit.

A more effective control of oscillation, however, is secured by varying the coupling between P and L_2 . By loosening the coupling between these two coils the tube can be stopped from oscillating and brought to the point of maximum regeneration. Conversely, tightening the coupling will increase regeneration and finally result in oscillation provided, of course, that the grid and plate circuits are in resonance.

The proper procedure, therefore, for tuning in a station is to use maximum coupling between coils P and L_2 while varying the two variable condensers until the desired signal is heard. Then loosen the coupling between P and L_2 until the detector tube stops oscillating. At this point a slight final re-adjustment of the plate and grid tuning condensers may be necessary.

While tuning in stations operating on differing wavelengths take note of the value of the coupling necessary for maximum regeneration at each different wavelength. It will be found that this critical degree of coupling will vary according to the wavelength of the station being received; and that the coupling between coils P and L_2 necessary for maximum regeneration is greater for the longer wavelengths. In other words, the longer the wavelength of the station being received the tighter must be the coupling between coils P and L_2 in order to secure maximum regeneration and, conversely, as the receiver is tuned to shorter wavelengths the degree of coupling necessary for maximum regeneration becomes less.

EXAMINATION - LESSON 34

1. How does feed-back take place in the circuit shown in Figure 2?
2. What is the purpose of coil P in Figure 2?
3. State briefly two ways in which regeneration can be controlled.
4. How is the plate circuit tuned in Figure 2?
5. What advantage is derived from making the coil P, in Figure 2, rotatable?
6. What is the purpose of the tuned circuit $L_2 C_2$?
7. When the plate and grid circuits in Figure 2 are both tuned to the same wavelength, how can oscillation be prevented?
8. How is oscillation controlled in Figure 1?
9. (a) What are the three principal internal capacities in a vacuum tube?
(b) Are these capacities large or small?
10. What is the purpose of condenser C_1 in Figure 1?